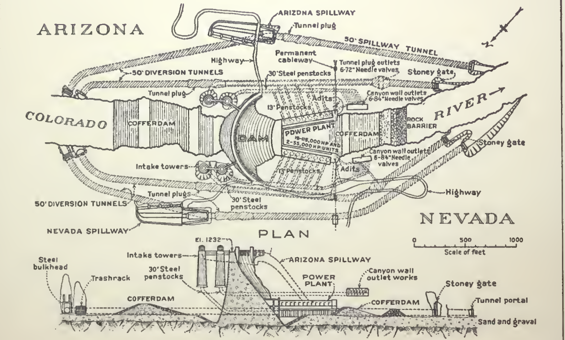
CONSTRUCTION OF

BOULDER DAM

PREPARED IN COLLABORATION WITH THE

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION



LONGITUDINAL SECTION

BOULDER DAM AND APPURTENANT WORKS

7-7-33

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INDEX

Black Canyon, 1921

LOCATION

Boulder Dam is being built by the United States Government ln the Black Canyon of the Colorado where the river forms the boundary between the states of Nevada and Arizona. The location is 450 miles from the Gulf of California, 260 miles downstream from Bright Angel crossing in Grand Canyon, 30 miles southeast of Las Vegas, Nevada, and 7 miles northeast of Boulder City.

THE BUILDERS

The Bureau of Reclamation, a part of the Department of Interior, furnishes complete designs, lays out and stakes all structures, exercises general supervision of construction, maintains close inspection of all project operations, furnishes all materials, and makes payment to the contractor at monthly intervals for work completed.

Contracts are awarded to lowest bidders for actual construction on the project and for furnishing all materials that form a part of the permanent structures. The principal labor contracts ln force are with the Six Companies, Inc., of San Francisco, California, for building the dam, power plant and appurtenant works, at a bid price of approximately $50,000,000.00 and with The Babcock & Wilcox Company of Barberton, Ohio, on its bid of approximately $11,000,000 for furnishing and erecting the plate steel pipes to be used to supply water to the turbines of the power plant or otherwise regulate the flow of water from the reservoir.

MATERIALS REQUIRED

Quantities of materials to he removed or placed during construction include 9,000,000 tons of rock excavation, which if placed in a masonry wall, similar to those on the project, would extend 2,500 miles; more than a million cubic yards of river fill excavation, equivalent to digging a trench 100 feet wide, a mile long, and 60 feet deep; and over 4,000,000 cubic yards of concrete, sufficient to build a 20-foot wide pavement extending from California to Florida.

Supplies for building the huge structure include 5,000,000 barrels of cement, 165,000 cars of sand, gravel and cobbles, 35,000 tons of structural and reinforcing steel, 900 cars of hydraulic machinery, and over 1,000 miles of steel pipe. If the total materials and construction equipment were placed in one train, the

East Section, Boulder City

engine would be arriving at Boulder City as the caboose left Kansas City, Missouri.

Government Administration Building

COST

The estimated cost of construction is $120,000,000.00 including $11,200,000.00 interest charges for the period in which the project is liquidated. Contracts for power have been signed by the City of Los Angeles, and other municipalities, the Southern California Edison Company and the Metropolitan Water District of Southern California that will insure revenues to pay all construction charges and interest in less than 50 years.

PREPARATORY CONSTRUCTION

In order to move the immense amounts of materials and heavy equipment required, secure ready access to the canyon activities, furnish cheap construction power, and provide livable quarters for the workers in the desert climate, it was necessary to build railroads and highways, a long electrical transmission line, and the construction camp of Boulder City.

Standard gauge tracks were laid by the Union Pacific Railroad from its main line to Boulder City, lengthened by the Bureau of Reclamation to the top of the damsite and later extended by Six Companies, Inc., to the bottom of Black Canyon and to all its plants, completing the 52 miles of line that serves the project. Nearly 300 cars of materials are now carried by rail to the construction features every twenty-four hours.

Paved roads lead from U. S. Highway 91 at Las Vegas to Boulder City, 23 miles to the southeast, and thence to the top and bottom of Black Canyon. Visitors to the project in 1933 numbered 132,000, and over 30,000 in March, 1934.

A transmission line, 222 miles in

West Section, Boulder City

Government Residences

length and operated at 88,000 volts, brings electrical energy from San Bernardino, California, to a substation near the top of the Nevada dam abutment, where it is distributed to Boulder City and construction features at 2,300 volts. The government and contractor use more than 4,000,000 K.W.H. of electricity each month, costing in excess of $45,000.00.

The construction camp of Boulder City has been laid out at a location seven miles from Black Canyon and 2,000 feet in elevation above the river channel, where the climatic and soil conditions are the most desirable in the vicinity of the damsite. The governmental section of the town is built in a permanent manner, as it will be used to accommodate those employed at the dam, power house and reservoir after they are completed. All land in and near Boulder City is government owned and the contractors, permittees for business enterprises, and non-government residents lease the ground on which their buildings are located. The area is under strict supervision and regulations are enforced by a body of Federal Rangers.

The population is more than 6,000 persons, of whom 40% of the men are unmarried. The large dormitories of Six Companies, Inc., are air cooled and heated, and accommodate 172 men, each in a single room. The mess hall, operated by Anderson Brothers Supply Company, has seating facilities for 1,300 men and serves during seven times a day, a total of nearly 6,000 meals. Each single man is charged $1.60 a day for meals, room, and transportation to and from the canyon. Married men rent houses from the contractor at rates varying from $15.00 to $50.00 for two to six-room houses unfurnished, and may buy their food and other supplies

One of the Mess Halls

Dormitory

150-Man Transport

locally. Approximately 4,000 men are employed by the government and contractors, the gross pay roll each month exceeding $600,000.00.

The water supply for the town is procured from the Colorado River. Starting from the intake pumps, carrying an average content of 6,000 parts per million of silt and 350 parts per million of hardness the water passes through a desilting plant, and is pumped 1,800 feet in elevation through a six-mile pipe line to a modern filtration plant. Here it is softened by the addition, principally of soda ash and hydrated lime, is filtered through sand beds and then chlorinated before being lifted an additional 200 feet to a 2,000,000-gallon distribution tank on the hill north of the town. The per capita consumption is approximately 190 gallons per day during the summer months and 130 for the year.

PLANT OF SIX COMPANIES, INC.

In order to build the dam, power plant and accessory features in an efficient and economical manner and within the time specified by the government contract, Six Companies, Inc., has built highways and railroads, erected machine shops, air compressor plants, garages and warehouses, spanned the canyon first by bridges and later with cableways, constructed a gravel screening plant and two mixing plants, acquired power draglines and shovels, trucks, cars, derricks, cranes and similar machines, and designed many original appliances for particular

Cableways Nos. 5 and 6

Skip Load of Men

Load of Concrete

needs. Many trucks of the contractor will transport 16 cubic yards in one load, and two are of 50-ton capacity. Undoubtedly this is the greatest massing of specialized equipment ever witnessed on any construction project.

Ten miles of paved highways and 20 miles of standard gauge railroad were

Arizona Sand and Gravel Deposit

Screening and Washing Plant

built connecting all plants with the canyon activities. The railroad equipment includes 150 dump cars and eleven 100-ton steam locomotives, as well as four gasoline and eight electric locomotives.

Means of transportation for men and materials across the river and from canyon rim to river channel were provided first by boats and barges, later by steel suspension bridges, and small cableways, and finally by heavy duty cableways of unique design.

The latter are five in number, are operated with loads up to 25 tons and are so located and devised that supplies may be deposited at any point in the spillway open sections, intake tow-

Low Level Concrete Mixing Plant

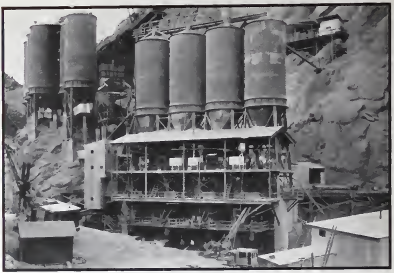
ers, the dam and powerhouse. All of the towers, at terminals of the 3-inch diameter track cables, are movable except the one head tower farthest downstream on the Nevada side. The movable end structures are built of steel and the largest are 32 feet by 46 feet in base plan and 90 feet high.

The towers travel on parallel tracks and the Nevada and Arizona structures of each of the four upstream cableways move in unison. The tendency of a tower to overturn is counteracted primarily by concrete blocks, weighing over a million pounds, placed above the rear track, and by raising the front rail of the front track, or by a central truck bearing against an anchored central rail laid with web horizontal. All five cableways are operated from the head towers located on the Nevada side and are controlled by telephonic orders from men in view of the loading or unloading activity. In their few years of use they will be required to convey more than eight million tons of supplies and materials.

SCREENING PLANT

Six Companies, Inc., is required to furnish all concrete aggregates of sand, gravel and cobbles, and to secure these materials from a deposit on the Arizona side of the river approximately 10 miles upstream from the dam. For this purpose, the contractor has built a sand and gravel screening and washing plant at a three-way junction on its railway system where one line leads to the Arizona deposit, another to the bottom of Black Canyon and the third to the U. S. Construction Railroad, which connects Boulder City with the top of the damsite.

Principal features of the plant are a crusher for oversize rock, a series of structural steel towers connected by belt conveyors and equipped with large vibrating screens, a battery of sand washers and classifiers, and a system of stockpiling, reclassifying aggregates and loading into railroad cars. Materials from the deposit are loaded by a 5-cubic yard electric dragline into trains of ten 50-ton dump cars and hauled across seven miles of standard gauge line, including an 800-foot pile trestle bridge over the river, to the screening plant. Here the screens separate the pit run into sand, three sizes of gravel and 3-inch to 9-inch cobbles, and convey these classified aggregates to stock-



Blending Plant and High Level Mixing Plant

piles. Later they are hauled by train direct to the mixing plants or to storage piles. Some of these latter are near the plant and others are above the high water surface of the reservoir, along the railroad line to the top of the damsite.

The plant is the largest of its type ever built and classifies materials at an average rate of 700 tons an hour and a maximum of 1,000 tons an hour.

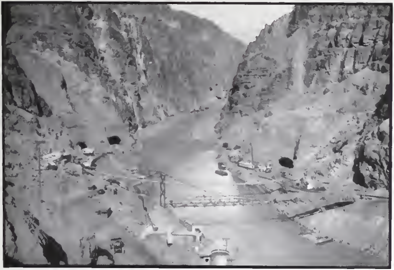
MIXING PLANTS

Concrete mixing plants of the contractor are two in number, one of which is located near the bottom of the canyon, 4,000 feet upstream from the dam and the other on the Nevada rim of the canyon 600 feet downstream from the damsite. Both are equipped in the most modern manner with immense storage bins for aggregates, automatic weighing batchers, automatic recorders and several 4-cubic yard mixers.

The aggregates of sand, gravel and cobbles are transported from the track hoppers to the bins in the low level plant by long belt conveyors, but are dumped directly from the railroad cars into the aggregate bins at the high level plant.

Water is secured from the Colorado River, desilted in the contractor's treatment plant and pumped to storage tanks near each mixing plant.

Cement is purchased by the government from lowest bidders in 350,000 barrel to 1,500,000 barrel contracts and shipped in bulk to a cement blending plant situated on the south side of the aggregate bins at the high level mixing plant. The cement is unloaded and conveyed to the silos of the blending plant by compressed air pumps, passes through vane feeders beneath the silos to helical conveyors which mixes the cements from each silo and delivers the product to a Fluxo pneumatic pump. The latter machine then transports the cement through a 6-inch pipeline to the silos of the high level plant or through a 9-inch line a mile in length, including a drop of 500 feet, to the low level plant. The flow through this latter line is at the rate of 450 barrels of cement an hour.



View Upstream February, 1932, Showing Tunnel Outlets

Drilling Jumbo

Drilling Jumbo at Tunnel Face

The purpose of the blending plant is to combine cements of different chemical characteristics or to mix the same type from various factories to secure a uniform product.

When the mixing plants are in operation the aggregates, water and cement are fed first into batchers which automatically fill to the designated weight, then pass to a mixer hopper and into the mixer. After a 2½-minute mixing period the resultant concrete is dumped

into buckets and transported to the pouring site. The weights of cement, water and aggregates, and the relative amount of water (consistency) of each concrete batch are automatically recorded.

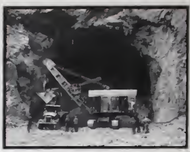
The low level plant contains three 4-cubic yard mixers and the high level plant five of the same size, making possible the production of 32 cubic yards (64 tons) of concrete in 3 minutes, or a theoretical daily capacity of 13,150 cubic yards. If mixed for the dam this volume of concrete would require 44 cars of cement, 418 cars of aggregates, and 350,000 gallons of water. The actual maximum output in one day has been in excess of 10,000 cubic yards.

FEATURES OF CONSTRUCTION

Principal features of construction are the four diversion tunnels, two on each side of the canyon, to detour the river around the damsite during construction; the cofferdams, one above the damsite, the other below, to turn the river into the diversion tunnels and keep the damsite dry; the dam which will raise the river water surface a maximum of 584 feet; the two spillways, one on each side of the canyon, to carry the reservoir overflow; the four intake towers to take water from the reservoir for the turbines of the power plant, for downstream requirements and for reservoir regulation; the penstock and outlet system that will carry water from the intake towers to the power plant or to outlet works; and the U-shaped power plant which will nestle close to the walls of the canyon immediately downstream from the dam.

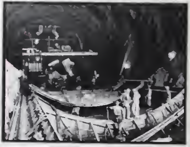
PROGRAM OF CONSTRUCTION

The general program of construction, all features of which are overlapping, is to drive and line the four diversion tunnels, build the cofferdams, excavate the dam abutments and river channel, build the dam, construct the spillways, intake towers, penstock and outlet system, outlet works, power house and finally install the plug outlet works and its related pipes in the Nevada inner diversion tunnel. After the intake towers and canyon wall outlet works are completed and the connecting pipe line installed, the steel bulkhead gates may be lowered at the inlets of the two diversion tunnels farther from the river, the Arizona inner tunnel will be plugged and water may start rising

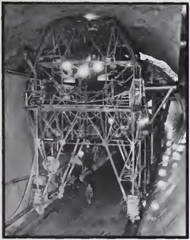


Tunnel Excavation

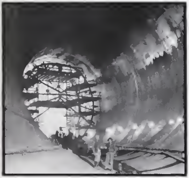
Completed Excavation



Lining Invert and Sidewall



Arch Lining . . . Gun Carriage in Foreground



Completed Tunnel

back of the partially completed dam under control of slide gates installed in a plug in the Nevada inner diversion tunnel. When the water in the reservoir rises to the gates in the bases of intake towers, 260 feet above the river bed, the slide gates in the plug will be closed and the flow downstream from the dam regulated by intake tower gates and canyon wall needle valves.

EXCAVATIONS FOR DIVERSION TUNNELS

The contract for construction of the dam, power plant and appurtenant works was awarded Six Companies, Inc., on March 11, 1931, and by May 16, 1931, the contractor had erected a temporary camp, built pioneer roads to the damsite and started excavations for the diversion tunnels. The first operation for this latter work was to drive 12-foot by 12-foot pilot tunnels as top headings, starting from all portals and from intermediate points reached through adits driven in canyon walls, thus securing sixteen faces where excavations could proceed. Headings were then enlarged to 41-foot by 56-foot sections, starting at all portals and finally the remaining 15 feet in the invert was removed and the tunnel trimmed to the full 56-foot diameter.

Specially built equipment, termed "Jumbos," were originated by the contractor for this work. The one for drilling the 41-foot by 56-foot headings mounted 30 compressed air drifter drills, was transported by a 10-ton truck, and by means of this equipment, 110 holes 20 feet deep could be drilled and loaded in 4 hours. Each blasting round broke an average tunnel length of 17 feet, loosening 1,000 tons of rock which was mucked in 4 hours by a 3½-cubic yard electric shovel and a fleet of 8- and 10-cubic yard trucks.

All 41-foot by 56-foot headings were holed through on April 6, 1932, and the four tunnels were excavated to full section by May 27, 1932. Rock removed amounted to 1,500,000 cubic yards, requiring 3,561,000 pounds of dynamite, or 2.38 pounds of powder per cubic yard.

LINING DIVERSION TUNNELS

Lining the tunnels with a 3-foot average thickness of concrete was accomplished by forming and pouring the invert section in the ordinary manner, similar to that used for concrete highways and sidewalks; then pouring the side walls behind huge steel forms, weighing 250 tons per 80-foot section; and finally building the arch by forcing concrete above massive steel forms by compressed air at 100 pounds pressure per square inch.

The low level mixing plant produced

all concrete for tunnel lining, and transportation from the plant was first by truck and then by gantry crane. Buckets used were of the 2-cubic yard spout type or 4-cubic yard agitators. Curing of finished concrete was secured by spraying with water or painting the surface with an asphalt mixture (Hunt process). After lining, holes were drilled through the concrete into the rock and a cement and water grout was forced into all rock crevices and openings around the tunnel. Approximately 300,000 cubic yards of concrete were placed in the diversion tunnel linings in a period of 368 days.

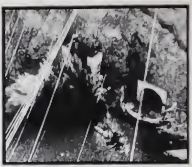
DIVERSION

By November 13, 1932, eighteen months after the first excavation, the Arizona tunnels were ready to carry the river flow, and simultaneous blasts on that date at inlets and outlets signalized the first diversion. Preceding that event, a pile trestle bridge had been thrown across the river a short distance downstream from tunnel inlets and soon after a part of the river started pouring through the Arizona tunnels, trucks commenced dumping muck from the bridge to form a temporary barrier and force the entire flow out of the old river bed. Within twenty-four hours the bridge was covered by a dam which was raised and widened until practically all seepage was eliminated. Another temporary dam of earth and tunnel muck was meanwhile pushed out from the Arizona to the Nevada side at a location upstream from the tunnel outlets. The water entrapped between the two temporary barriers was then pumped out and excavations were started across the entire channel for the upper and lower cofferdams.

COFFERDAMS

The centerline of the crest on the upper cofferdam is 800 feet upstream from the axis of Boulder Dam and 650 feet downstream from the nearest tunnel inlet. The crest of the lower structure is 1,320 feet downstream from the main dam and 700 feet upstream from the nearest tunnel.

The essential characteristics of both cofferdams are thick fills of rolled earth, the long slopes of which are protected by a concrete slab or rock



Initial Blast for Diversion

Building Temporary Dam for Diversion

fills. Concrete percolation stops extend from base to crest at each canyon wall to impede the possible flow of water along the walls. The upstream slope of the upper cofferdam is faced with a 6-inch reinforced concrete slab, of 4 acres in extent, and a sheet steel piling cutoff is driven to bedrock across the upstream toe. Concrete curbs and rubber seals connect the face paving with the canyon walls and steel piling. The downstream slope of the lower cofferdam is protected from eddy flow of the river by a massive barrier of 90,000 cubic yards of rock built immediately downstream. The slopes of both cofferdams toward the main dam are covered with heavy rock fills.

Excavations for the upper cofferdam

Temporary Dams in Place

Building Upper Cofferdam

were carried down to a consolidated gravel foundation 18 feet below the river bed and the removed material transported by truck and train to dump grounds 3 miles up the river. Sand, gravel and clay from deposits in Hemenway Wash, four miles upstream, were hauled by train and truck to the cofferdam, spread by bulldozers on caterpillar tractors, dampened by hose, and rolled by 6-ton sheep's foot rollers. As many as 40 trucks, 4 trains and 5 power shovels worked day and night for two months to complete the fill, moving 510,000 cubic yards of earth, including one 24-hour run of 18,000 cubic yards.

Rock secured from nearby excavations was placed in riprap formation on the upper slope and dumped on the downstream slope. The last work for the structure was the placing of the face paving and rubber seals and completion of the rock fill on the downstream slope. Construction of the lower cofferdam was conducted in much the same manner as for the upper structure, taking into consideration the differences in design previously mentioned.

Dimensions of the upper cofferdam are 750 feet thick at the base, 480 feet wide, 98 feet high, and 70 feet thick at the crest. The lower cofferdam is 500 feet thick at the base, 66 feet high, and 50 feet thick at the crest. The rock barrier has a base thickness of 210 feet and a height of 54 feet. The cost to the Government for the diversion tunnels and cofferdams was nearly twenty-three million dollars.

When diversion of the river is no longer necessary, the lower cofferdam and rock barrier will be removed and the excavated material hauled out of the river channel. The upper cofferdam will remain in place.

HIGH SCALING

Stripping loose and projecting rocks from the walls of the canyon to protect workers and prevent damage to canyon structures was one of the most hazardous and the most spectacular of all work on the project. Men were lowered by cableways or climbed to their work "over the ropes" where, suspended by safety belts or in bosun chairs, they drilled for blasting and pried off all loose rock.

Stripping was carried on from canyon rim to canyon floor above all structures and the scaling methods were used for excavations of the tunnel portals, dam abutments, intake towers, canyon wall outlet works and power house. "High Scalers" employed for the work, in April, 1933, numbered approximately 400.

DAM EXCAVATION

Excavations for the dam abutments were started after the river was diverted and completed shortly before cofferdams were built. The cuts are on radial lines of the dam axis at the top,

Completed Upper Cofferdam . . . View Downstream

View at Outlets. Tunnels Carrying 79,000 Cubic Feet a Second

Scaling Above Power House

Blast on Canyon Walls

where the water thrust against the dam will be carried primarily by arch action, and are warped to the normal canyon wall in a drop of about 300 feet, the dam section at the base being designed to withstand the water thrust by the weight of the structure.

Safely entrenched between the cofferdams, the excavations in the river channel proceeded at a rapid rate. Power shovels, draglines and trucks labored the full twenty-four hours, digging from river bed at elevation 640 down to bedrock on each side of the canyon at elevation 600 and on downward in the 80-foot wide middle gorge nearly a hundred feet more to the low point at elevation 505.6. The sand, gravel and rock removed amounted to more than a half million cubic yards and were hauled by truck to train and transported three miles upstream to a dump ground. During this work, the contractor's average bills per month were $15,000.00 for tires and $1[illegible] for gasoline.

DAM CONCRETE

The exposed bedrock was [illegible], forms were built, and on June 6, [illegible], the first 16-ton (8 cubic yard) bucket of concrete for the dam was mixed at the low level plant, transported by train beneath cableway No. 6, picked up, swung part way across the canyon, lowered to position and dumped at the signal man's order. Other trains and cableways were brought into action, a 20-ton derrick with 138-foot boom was later added for transference at the upstream face, and by August 31 the middle gorge was filled, seven months after starting, a million yards had been placed, and three and a half months later, half of the concrete for the structure had been poured. The average

placement in 24 hours is approximately 7,000 cubic yards and over 8,000 cubic yards have been poured in that time.

Completion of the dam structure is expected before the summer of 1935, thus in less than two years, 1,200 men and modern machinery will have placed 3,220,000 cubic yards of concrete, a greater volume than that of the Great Pyramid of Egypt, which, according to Herodotus, required the services of 100,000 men for 20 years in its construction.

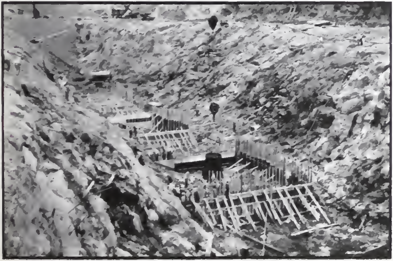
The dam is of the arch gravity type, the radius of the axis being 500 feet and weight approximately 6,500,000 tons. When completed it will be 727 feet high, 650 feet thick at the base, 1,180 feet long and 45 feet thick at the crest and will raise the water surface 584 feet. For comparison, its height is 1½ times that of the Los Angeles City Hall and only 65 feet less than that of the Woolworth Building in New York City. The base thickness is greater than two normal city blocks and its

Scaling

Debris in Canyon, Following Excavations on Canyon Walls

Excavation for Dam Foundation

Dam Excavation Practically Completed



Pouring First Bucket of Dam Concrete

16 Tons Concrete in Transit to Dam

crest is four blocks long. The dams of its nearest height are the Owyhee, near Ontario, Oregon, which rises 405 feet above bedrock and the Sautet Dam of 446 feet height now under construction in France.

COOLING AND GROUTING THE DAM

The magnitude of the structure is outstanding and the unusual plan of construction presents features of similar note. The vast bulk of the dam has provided a problem in temperature stresses that required much thought and research before a solution was attained. The temperature of the concrete, using standard Portland cement, is raised approximately 40° by the chemical action of setting, and if the dam were allowed to cool naturally, a period of as much as 150 years would elapse before the temperature of the mass reached that of the surrounding medium. During all that time, temperature stresses would be set up, and cracking would result from differential cooling.

To obviate this condition, the dam is built in a group of vertical columns 25 feet to 60 feet in plan, one inch diameter cooling pipes are placed at 5-foot intervals vertically and 5 feet 9 inches horizontally throughout the structure, and grout pipes are installed leading to the sides of all columns.

Water from an atmospheric tower at slightly below air temperature is first passed through the 1-inch lines until maximum cooling is secured by this means, then water from a refrigerating plant at a temperature of 35° to 40° F. is turned into the lines, cooling the concrete as low as 42° F. The 14-inch supply lines for the cooling loops are located in the 8-foot slot that passes through the center of the dam. The slot is filled with concrete in 50-foot lifts as soon as cooling of the dam has been completed for that lift.

After a section of the dam, for example from elevation 600 to 650 has been cooled to the specified temperature, the slot is poured to the higher elevation, and a water cement mixture of grout is forced through the grout pipes into the cracks opened up between the columns by the contraction due to cooling. The section thus cooled and grouted is then allowed to resume the temperature of the surrounding medium and the resulting expansion, carried from column to column by the joint filling of grout, places all components of the concrete in compression and prevents cracking, which normally ensues from the opposite or tensile force. Another effect of the cooling and grouting is to force the sides of the dam into close contact with the canyon walls.

The atmospheric tower for the cooling system is located on the lower cofferdam, and the refrigerating plant on a canyon wall bench, just upstream from the cofferdam on the Nevada side. The plant is equipped with three complete ammonia refrigerating units and one standby unit, as well as all pumps required for forcing the water from the cooling water tower through

Dumping 16 Tons of Concrete

Pouring with Agitator in Constricted Area

Final Clean-Up of Dam Pour

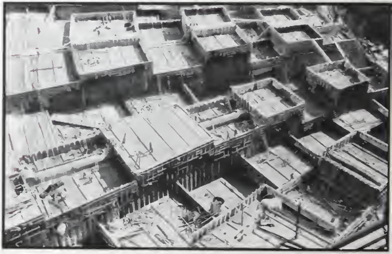
the cooling lines and for circulating the refrigerated water. The cooling capacity of the plant is equivalent to producing 1,000 tons of ice in 24 hours. The rate of flow through each cooling loop is four gallons per minute. Three thousand gallons from the tower and an equal amount of the refrigerated water may be circulated through the dam at one time. The length of cooling pipes in the dam will be approximately 580 miles, and grout pipes 200 miles.

Electrical resistance thermometers, strain meters and contraction joint meters are installed in the dam, and records maintained by government engineers. These instruments furnish information of present construction as well as provide data for future design.

View Downstream September, 1933 . . . Note Cooling Plant and Tower on Lower Cofferdam

Dam Approximately 200 Feet High
November, 1933

Slot Through Middle of Dam . . . Note Supply Lines for Cooling Pipes



Dam Columns and Galleries

Looking Down Nevada Abutment Toward Upstream Face

Upstream Face of Dam on Nevada Side

Upstream View of Dam when Approximately 300 Feet High, March, 1934

Recent Ups

ew from Airplane (C) Spence Air Photo

Boulder Dam View from Arizona Rim

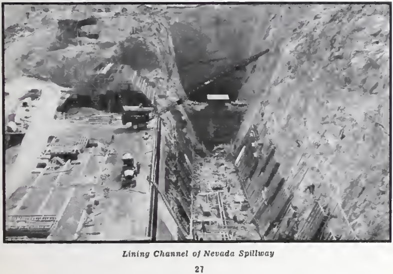
Excavation for Nevada Spillway Looking Toward Inclined Shaft

SPILLWAYS

Flow of water from the reservoir will normally be regulated by the amount required for the turbines of the power plant or be by-passed around the plant through the needle valves in the outlet works, to satisfy downstream demands or to lower the surface of the reservoir. Under exceptional conditions when the reservoir is full as a result of unusually large floods, or if it is deemed advisable to lower the surface in advance of a threatened flood, the reservoir overflow will pour over weirs into spillway channels, plunge 500 feet down inclined shafts to outer diversion tunnels and emerge in the river channel below the dam.

Each spillway is capable of passing 200,000 cubic feet per second of water, equal to the maximum recorded flow through Black Canyon. More than 11,000,000 horsepower, in terms of falling water, would be released by a spillway operating at capacity and the velocity of flow as the water passed into the diversion tunnel would be at the rate of 175 feet per second or 120 miles per hour.

The length of a spillway is approxi-



Lining Channel of Nevada Spillway

Completed Lining—Nevada Spillway

mately 650 feet in open section and the concrete lined channel is 150 feet wide at top and 125 feet average depth. The largest battleship could be floated in the structure if the inclined shaft were dammed at the portal. The Arizona shaft is 88 feet high and 98 feet wide at the portal and narrows gradually to a 50-foot diameter. A concrete plug, 400 feet long, will be placed in the diversion tunnel immediately upstream from the intersection with the inclined shaft.

Four steel drum gates, each 100 feet long and 16 feet high, and weighing a half million pounds, are erected on each spillway crest. The gates ordinarily lie in weir recesses and are hydraulically raised by the rising waters of the reservoir. The elevation of the permanent crest is at 1205.4 feet above mean sea level and top of the gates, when raised, at 1221.4 feet or 10.6 feet below the Boulder Dam crest.

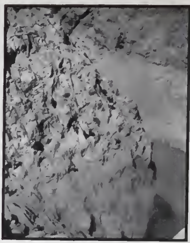
The spillway channels were blasted from solid rock, using the drill jumbos from the tunnels and removing the

Intersection Nevada Spillway Shaft and Diversion Tunnel

INTAKE TOWERS

flow to the turbines. Excavations were conducted by scaling methods, the muck being dumped into the canyon below, loaded by power shovels and hauled by trucks to dump grounds in side canyons above the high water surface of the river. Each cut is 110 feet in diameter at the base and those on the Nevada side are 300 feet in depth.

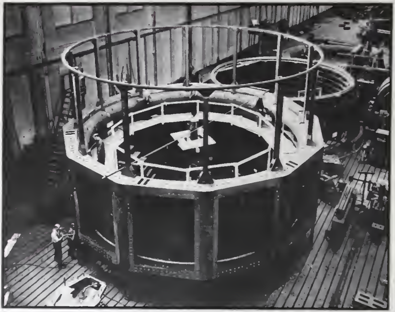
Essentially the towers are hollow cylinders 380 feet high, 85 feet in diameter at the base and are equipped with cylinder gates at the bases and 150 feet higher. From the exterior they resemble fluted columns as 12 recesses, formed by the tower fins, extend from base to top. Trash racks will be installed in these recesses to prevent debris from entering the gate openings. Slides are also placed in each fin from top to bottom of the tower, down which emergency gates can be lowered to isolate any gate for repairs. The cylinder gates are 32 feet in diameter and 11 feet high, each weighing approximately a half million pounds.



Scaling for Intake Towers

Completed Excavation for Nevada Intake Towers

PENSTOCK AND OUTLET SYSTEM



Tower Gate and Entrance Liners at Factory

supports for most of the tunnel length, but is to be anchored by filling the spaces between pipe and tunnel lining in the vertical curve below the tower, upstream and downstream from penstock openings, and from the construction adit downstream. The length of the penstock and outlet header tunnel is 1,550 feet on the Nevada side and 1,375 feet on the Arizona side.

The four penstock tunnels that branch from the penstock header tunnel are excavated to 21-foot diameter and lined with 18 inches of concrete. Pipes, 13 feet in diameter, rest on supports poured monolithic with the lining and run from the 30-foot pipe to butterfly valves in the power plant. The pipes are anchored just below their upper ends and immediately above the canyon wall tunnel portals. Lengths of the inclined penstocks are approximately 330 feet in Nevada and 310 feet in Arizona.

The construction adit is 26 feet wide, 43 feet high, 150 feet long and will be lined only in the floor section. Its purpose is to provide means of access to the header tunnels for installing the 25-foot and 30-foot pipes.

Outlet tunnels, six in number, are horizontal, 140 to 175 feet in length, have been excavated to a 13-foot horseshoe section and will not be lined. Outlet conduits, 8½ feet in diameter are centered in the tunnels and the space between pipe and rock filled with concrete. A slide gate and 84-inch needle valve will be installed at the river end of each conduit. The canyon wall outlet works, containing the needle valves, will be erected on a bench cut in the canyon wall 168 feet above the old river bed. Access to the valve house will be gained from the power house through an adit and elevator.

The penstock header from the upstream intake tower leads downward on

[illegible]

[illegible]

[illegible]

[illegible]

Intersection . . . Incline from Nevada Tower and Diversion Tunnel

Arizona Construction Adit

tion adit, the portal of which is located directly below the construction adit previously mentioned, have been driven from the diversion tunnel to canyon wall. After the diversion tunnel has filled its purpose of carrying water around the damsite, a concrete plug 300 feet in length will be poured directly upstream from the penstock header tunnel from the tower and another built at a location 675 feet upstream from the tunnel outlet. The lower plug will be equipped with six slide gates and 72-inch needle valves. Access from the power house to the plug will be through a concrete lined adit.

In like manner to the upper penstock header, a 30-foot steel pipe will run from the upstream intake tower through the inclined tunnel and diversion tunnel past the penstocks and construction adit to a 25-foot outlet header which will divide at its downstream end into three 13-foot and then six 7½-foot pipes leading to the needle valves in the plugs. The pipe will be anchored by a concrete filling between pipe and lining in the inclined tunnel, at locations upstream and downstream from penstock openings, downstream from the construction adit, and at the plug.

The penstock tunnels are approximately horizontal but the construction adit drops downward a vertical distance of 45 feet from canyon wall to diversion tunnel. The penstocks and adit were excavated, the penstocks lined, and the 13-foot pipe will be installed in the tunnels in a manner similar to that previously described for the upper system.

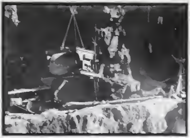
Excavations of the construction adits and upper penstock header tunnels were accomplished with drilling jumbo equipment, small 1¼-cubic yard power shovel and 8-cubic yard trucks. The jumbo was equipped with 30 compressed air drills and a heading 41 feet wide by 36 feet high was drilled and loaded in one setup. Muck was loaded into trucks by the power shovel, hauled through the con-

struction adit to the canyon wall, dumped into the canyon below, reloaded into trucks and hauled out of the canyon.

The inclined header tunnel from the upstream tower was excavated by driving a 7-foot by 14-foot top heading from the arch of the diversion tunnel, enlarging downward to the floor of the incline, and breaking the remaining sections into the slot thus formed, starting from the top and working downward on horizontal benches. The muck was removed from the diversion tunnel by power shovel and trucks.

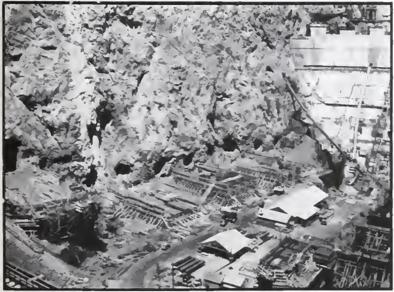
The smaller tunnels were driven by usual tunnel methods, using Conway muckers and trucks where permissible.

The upper header tunnels were lined to 37-foot diameter behind circular steel forms. The concrete was mixed at the high level plant, transported by truck and cableway to construction adit portal, placed on a car hauled by a storage battery locomotive, pushed to position at the foot of an inclined belt conveyor, and carried by belt to chutes for pouring invert and sidewall or to a compressed air gun for filling the arch section. The forms were moved on short sections of centrally located track, the ends of the tracks being supported by heavy structural steel columns.



Conveying Concrete to Penstock Tunnel

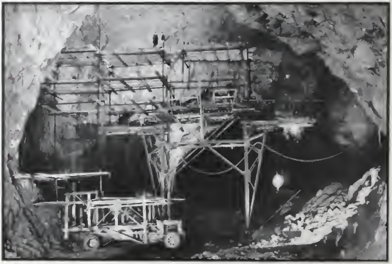
Lining for the inclined header tunnels was placed behind circular timber



Nevada Penstock Tunnel Outlets Back of Power Plant Construction

Arizona Outlet Works

forms for the sections through the curves. In the straight tunnel sections, concrete was poured first in the invert beneath wooden forms, followed by lining the sidewall and arch behind the circular forms. Lining was started at the foot of the incline and progressed upward. The forms were moved by hoists and, in the straight sections, travelled on rails set on the invert lin-



Excavation . . . Downstream Plug Arizona Inner Tunnel

Fabrication Plant of The Babcock & Wilcox Company

ing. Concrete from the high level plant was lowered from canyon rims by 15-ton derricks to a hopper above the upper end of the incline, from where the concrete flowed through zig-zag chutes to position.

Concrete lining in the horizontal penstock tunnels and the lower portions of the inclined tunnels was placed by a concrete pump behind wooden forms. The pump was located at the canyon wall inlet of a tunnel, received its concrete via cableway from the high level plant and pumped it through a 7-inch line to the back of the forms. Concrete for the upper sections of the inclined tunnels was conveyed to forms via zig-zag chutes running downward from the penstock header tunnel.

All the penstock header and penstock pipes will be installed within tunnels of sufficient size to allow inspection and maintenance.

FABRICATION AND INSTALLATION OF PLATE STEEL PIPE

All pipes for the penstock and outlet system are fabricated and installed by The Babcock & Wilcox Company of Barberton, Ohio, under contract with the Bureau of Reclamation. Most of the pipes are too large to be transported on existing railroads and are thus required to be fabricated on the project. The contractor has erected a plant for this purpose on the road from Boulder City to the dam, approximately 1½ miles from the top of the Nevada abutment.

Length of the plant with storage yard and connecting government warehouse is 970 feet, the width of the building is 90 feet, and height 85 feet. A visitors' gallery has been built across the west end of the plant which is accessible by a stairway on the outside of the building.

Plates of high tensile steel are shipped from the mills of the Illinois Steel Company at Gary, Indiana. In straight runs of pipe the plates for the 8½-foot and 13-foot units are approximately 11 feet long and of sufficient width (26.8 feet to 41.2 feet) to complete a section of pipe. The 25-foot pipe requires two plates for a section 11 feet long and the 30-foot pipe, three plates for a 10.5-foot length. Plates for some of the 30-foot pipe weigh 20 tons each, requiring one car for the transportation of only two plates.

Interior of Fabrication Plant

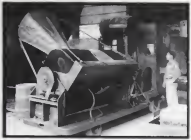
The first work of fabrication is marking the plates to designated patterns and size, shaping them as required and cutting a welding groove along the edges. This latter operation is performed by a specially designed planer 50 feet in length which is equipped with pneumatic clamps for holding the plate in place, and a cutting tool carriage on which the operator rides.

The plate is then conveyed by bridge crane to a 3000-ton hydraulic press where the ends are bent to the prescribed radius, followed by rolling the plate to the required form in a vertical roller 12½ feet in height. The rolled plate is placed on a curved form, tack welded at the ends to other similarly rolled plates (when fabricating 25-foot pipe or over), turn-buckles are placed in position to hold the assembled plates to circular form, the section is turned on its side, placed on rollers and the longitudinal seams are arc welded by automatic welding machines.

After these seams are welded, any necessary stiffener rings are added, by welding, and a fabricated section, (or two or more if a bend is being built) are assembled end to end to form the finished pipe. Huge expansion appliances termed "spiders," are placed within each section to hold their ends coincident, the sections are tack welded together, and the girth seams then welded by the automatic machines. Butt straps, into which an adjoining pipe will fit when installed in tunnels, are shrunk on and welded to one section of the pipe preceding assembly and girth welding.

The succeeding operation, after welding has been finished, is to subject the longitudinal and girth joints to the scrutiny of a powerful X-ray which provides a photograph of the fusion weld and reveals any defects therein. The X-ray apparatus operates at 300,000 volts and is capable of producing radiographs of steel plate up to four inches in thickness. Any imperfections are chipped out, refilled with new metal,

Taking X-Ray Photograph of Weld



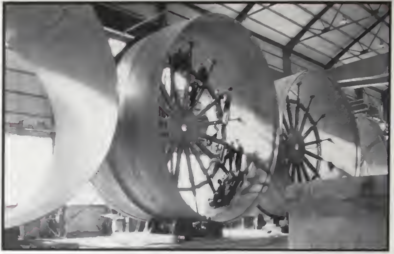
300,000-Volt X-Ray

X-rayed again and the photographs inspected.

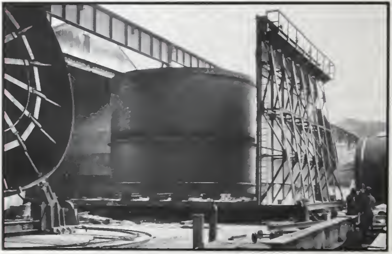
The required supporting brackets are then welded to the pipe, the section is picked up by one or more of the 75-ton bridge cranes and conveyed to a stress relieving furnace, placed in the oven, and the temperature raised to 1150° F. The pipe soaks at this heat for a length of time equal to one hour for each inch of thickness of the heaviest plate in the section, and is allowed to gradually cool during a period of several hours. This procedure relieves the stresses set up in the pipe by rolling and welding.

The final act of fabrication is the machining of the pipe ends to exact

Planer in Babcock & Wilcox Plant



Sections of 30-foot Diameter Pipe



Placing 30-foot Pipe in Stress Relieving Furnace

100-Ton Locomotive in 30-foot Pipe

185-Ton Trailer for Transporting Large Pipes

Government's 150-Ton Cableway

measurements by means of portable lathes inserted within the smaller sections or by a huge facing lathe, equipped with a 35-foot arm, for the 25-foot and 30-foot diameter pipes. The interior of the pipe is then shot blasted to remove all scale and coated with coal gas tar. The exterior is cleaned by air and wire brush, and painted with a primer coat of red lead.

All pipe of 13 feet diameter or less, are transported by railroad from the plant to a cableway pit on the Nevada rim, lowered by the Government cableway to cars at landing platforms and hauled to position by hoists.

The 25-foot and 30-foot pipes will be loaded on an 185-ton trailer, pulled by two 60 H. P. tractors to the Government cableway, lowered onto specially designed railroad carriages at landing platforms, taken sideways into penstock header tunnels or inner diversion tunnels, and pushed endwise into position.

For installation, the butt strap on one end of a pipe is heated by a gas ring and the end of the connecting pipe pushed within the strap. Both butt strap and included pipe are then fastened together by rivets or pressure pins and the outer end of the butt strap caulked water tight.

Anchors for the pipe are placed from

185 feet to 465 feet apart and the center connection between anchors is not made until the pipe is at a temperature of 50° F. or less. This temperature is approximately the same as that of the pipe when filled with water, thus reducing the temperature stress in the pipe to a minimum.

The weight of pipe to be fabricated amounts to 88,000,000 pounds or more than 900 carloads. Approximately 76 miles of electric welding will be required, using 1,000 tons of welding rod. Film for the X-ray photographs if placed end to end would extend 29 miles. The largest pipe section will be 30 feet in diameter, 22 feet long, have a plate thickness of 2¾ inches, and weigh 186 tons, including 5 tons of weld metal, nearly equal to the weight of two of the largest locomotives on the project.

GOVERNMENT CABLEWAY

The permanent cableway, built for Government use by contract with the Lidgerwood Company of Elizabeth, New Jersey, will be employed during the construction period for lowering the steel pipe, power house machinery, structural steel and other supplies, and later to convey replacements and new machinery for the power plant from canyon rim to landings downstream from the power house.

Location of the cableway is 1050 feet downstream from the dam crest and the track cables cross the canyon directly above the portals of all construction adits, where permanent concrete landings will be built. Its nominal rating is 150 tons, but loads of more than 200 tons, including track carriage and fall blocks, will be carried by the track cables. These latter are six in number, each 3½ inches in diameter, spaced horizontally at 18-inch centers. Their anchorage in canyon walls is accomplished by driving tunnels 50 feet to 80 feet long, excavating an eighteen-foot bulb at the ends of the tunnels, connecting the cables by plates and eye bars to a 13-foot by 13-foot structural steel grid in the bulb and pouring bulb and tunnel full of concrete. The pull on each canyon wall anchorage with a load of 150 tons at the center of the canyon is calculated to be 2,000,000 pounds.

The span between the Nevada head tower and Arizona anchorage is 1200 feet and the maximum lift approximately 600 feet. The track carriage weighs 19 tons and travels on 48 wheels. Lifting is done by two hoists, each 13 feet in diameter and 17 feet long, operating through an eight part line to the 5-ton fall blocks which are connected to the load. Conveyance across the canyon is accomplished by a third hoist and two endless cables. The hoisting speed is 30 feet per minute with loads of 40 tons or over and 140 feet per minute with lighter loads. Conveying speed is 240 feet per minute. Power is delivered at 2300-volt alternating current and transferred to direct current by a motor generator set. Each hoisting drum is driven by a 175 H.P. D.C. motor and the conveying drum by a 400 H.P. motor. Operation is by remote control from any of the five stations near landing platforms.

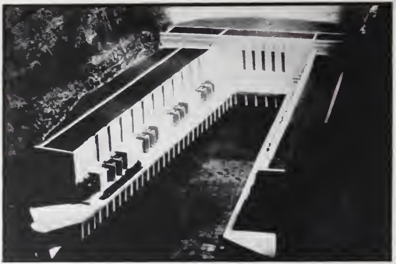
POWER PLANT

Construction of the power house has only begun, the excavations having been finished and concreting started. The building is being erected by Six Companies, Inc., but installation of machinery will be by Government forces.

The massive U-shaped structure of the power plant is located immediately downstream from the dam, the wings nestling against the canyon walls and the connecting section resting on the downstream face of the dam. The length of each wing is approximately 625 feet and the dam section 300 feet, or a total of more than ¼ mile.

Lowest concrete in any power house footing is at elevation 550 and the roof is at 780, a difference in height of 230 feet, or nearly 20 stories. The power house will rise 155 feet above low water surface. The roof will cover nearly 4 acres, (equal to two city blocks) and will be composed of eight laminations, two of these being reinforced concrete, another asphalt paving, another 18 inches of cork, others of sand and gravel, and the top of soil planted to grass lawn.

Installed capacity of the power plant will be 1,835,000 H.P. consisting of fifteen 115,000 H.P. units and two of 55,000 H.P. Four of the larger units and one of the smaller will be installed during the present period of construction and the others as required to supply the



Artist's Conception of Power Plant

growing demand for power. The turbines will operate under a maximum head of 582 feet, a minimum head of 422 feet, and an average head of 520 feet. The continuous firm power output upon completion of the plant is estimated to be 663,000 horsepower, which will require a continuous flow, at minimum head, of 17,000 cubic feet per second of water. This latter figure is approximately equal to the uninterrupted flow over a yearly period for 12,000,000 acre feet, the minimum active storage in the reservoir.

Materials to be furnished for present construction of the power house and plant comprise 227,000 cubic yards of concrete, 243 cars of reinforcing steel, 20,000 tons of machinery, and 9,000 tons of structural steel including 5 miles of 33-inch I beams and 88 trusses 67 feet to 73 feet in length. Among the items of machinery are vertical shaft, 150 r.p.m. turbines equipped with scroll cases 40 feet in width; generators of 82,500 k.v.a. rating to be operated at 13,800 or 16,500 volts and weighing 905 tons each; transformers to step up the voltage to 305,000 volts, weighing 205 tons each, and butterfly valves measuring 14 feet across the valve chambers.

SUMMARY

The first work for the present program of construction was initiated on July 5, 1930, two days after the first appropriation was made available by Congress.

The contract was awarded Six Companies, Inc., on March 11, 1931, the first excavations for diversion tunnels took place on May 16, 1931, the tunnels were excavated by May 27, 1932, and lined by March 8, 1933. Initial diversion occurred on November 13, 1932, the cofferdams were completed April 1, 1933, and the first concrete for the main dam structure was poured on June 6, 1933.

Under present plans, water will start rising back of the partially completed dam by February 15, 1935, and the first power will be generated in September of that year. All concrete will be poured in the dam by May, 1935, and all construction, except installation of power house machinery should be completed in 1936, at least eighteen months ahead

of the construction program outlined in the original schedule.

RESULTS

Completion of the project will solve many problems that have confronted communities and irrigated lands, in the regions downstream from the dam. The Colorado River when in flood is a dangerous, turbulent stream, but when the snows are melted in the headwaters, it dwindles to only a shadow of its former size.

In the delta region, near its mouth, the river runs on a rim above the Imperial Valley, and in 1905 broke through its silt banks, destroying lands and threatening inundation of the entire valley. Eighteen months unremitting toil and the expenditure of two million dollars were required to turn the stream into its old channel again.

Flash floods may occur in the Colorado River in any month, but generally the river flow is above the mean cnly from April to July. In the other eight months, it does not carry sufficient water for extensive irrigation or to assure a supply of domestic water for city use.

Another aggravation and tremendous expense to the farmers taking water from the stream, is the mud that is deposited in ditches and on the land. The average weight of silt carried by the river through Black Canyon is 300 tons a minute, or sufficient to cover 170 square miles a foot deep in one year. This load is deposited whenever the water velocity is reduced.

The fact has long been recognized that a solution to these problems was the construction of a high dam, but the project was not economically feasible until a market for power had been developed to carry the major construction charge by purchase of the electrical energy developed.

All these phases were considered in the design of the dam, reservoir and power plant. The dam will be built of sufficient height to impound 30,500,000 acre feet of water in the reservoir, an ample volume to control all upstream floods, store water for regulated distribution downstream and provide a basin for the deposit of silt. The dam, reservoir and power plant will have adequate proportions to produce 663,-

Transmission Tower Los Angeles Bureau of Power and Light

000 H.P. of firm electrical energy to pay all construction charges.

Contracts for power were signed, before Congress appropriated any funds for the project, with the City of Los Angeles, Southern California Edison Company, and Metropolitan Water District of Southern California.

The world's largest power transmission line is now being built, by the Bureau of Power and Light of the City of Los Angeles, from Boulder Dam to Southern California, where demands for large blocks of cheap power were instrumental in financing the Boulder Canyon Project.

Two rows of great towers, each carrying a single circuit, are under erection from Boulder Dam to Cajon Pass, a distance of 230 miles, and the remaining 40 miles to Los Angeles will be built with single towers, each supporting two circuits.

The line to Cajon Pass will require 2,411 steel towers placed in parallel rows and spaced 800 to 1,000 feet apart in each line. This type of tower is 109

Upstream View . . . Starting Construction

Upstream View . . . Fall of 1932

Upstream View . . . Summer of 1933

Upstream View . . . Recent

feet in height and supports cross arms 65 feet long, 90 feet above the ground. Towers in the line from Cajon Pass to Los Angeles will rise 144 feet from the ground, nearly the height of a twelve-story building.

During the past four years continuous research has been in progress by Power Bureau engineers, in cooperation with electrical engineers of America's greatest manufacturing establishments and the universities—more particularly the Harris J. Ryan Laboratory, at Stanford University—in an effort to determine the type of conductor best suited to the peculiar characteristics involved in the transmission of 275,000 volts over a distance of 270 miles. The highest voltage ever transmitted before is 220,000 to 230,000. The so-called Heddernheim type of conductor was selected. This is a hollow-core copper tube made up of interlocking spiral segments and has an outside diameter of 1.4 inches. Besides its virtue of comparative lightness, it possesses the inherent qualities of area sufficiently large to carry the electrical and mechanical loads involved and to minimize corona losses.

Work was started on the line June 3, 1933, following a loan of $22,800,000 from the Reconstruction Finance Corporation to the Bureau of Power and Light. Among the more important items of construction are 26,457 tons of structural steel, 1,626 miles of conductor, 1,000 miles of counterpoise, and 253,700 porcelain insulators, 10 to 10½ inches in diameter. Seven camps have been established along the single circuit section of the line, and more than 200 miles of new road will be built in virgin territory to transport men and materials to the scenes of construction.

Reservoir allocations are 9,500,000 acre feet for flood control, 5,000,000 to 8,000,000 acre feet for silt pocket, and 12,000,000 to 15,000,000 acre feet for water storage.

The deposition of silt in the reservoir will be tremendous, but if upstream development continues as it has in the past twenty years, the reservoir will be only one-tenth filled with silt at the end of 50 years.

Recreational possibilities offered by the lake behind the dam have not been mentioned among the other benefits, but will be of considerable consequence. The reservoir at high water level will cover an area of 145,000 acres, and have a shore line 550 miles in extent. The water near the surface will be clear and warm offering opportunities and inducements for boating, fishing, swimming and exploratory excursions into the relatively unknown regions bordering the lake.

PERSONNEL

Principal officials of the Government and contractors on the project engaged in construction of Boulder Dam are listed below.

Department of Interior

Secretary Harold L. Ickes, Washington, D. C.

Bureau of Reclamation

Commissioner Elwood Mead, Washington, D. C.

Denver, Colorado, Office

Chief Engineer, R. F. Walter.
Asst. Chief Engineer, S. O. Harper.
Chief Designing Engr., J. L. Savage.

Boulder City, Nevada, Office

Construction Engr., Walker R. Young.
Office Engineer, John C. Page.
Field Engineer, Ralph Lowry.
Chief Clerk, E. R. Mills.
City Manager, Sims Ely.

Six Companies, Inc.

President, H. W. Morrison, Boise, Idaho.

Boulder City, Nevada, Office

Director of Constr., Charles A. Shea.
Gen. Superintendent, Frank T. Crowe.
Asst. Superintendent, B. F. Williams.
Chief Engineer, A. H. Ayers.
Manager Boulder City Co., J. F. Reis.

Babcock & Wilcox Co.

President, A. G. Pratt, New York City.

Barberton, Ohio, Office

Vice President, Isaac Harter.
General Superintendent, J. E. Trainer.

Boulder City, Nevada, Office

Project Superintendent, R. S. Campbell.
Plant Superintendent, B. T. Kehoe.

ACKNOWLEDGMENT

Grateful acknowledgment is hereby made to the Bureau of Reclamation, Six Companies, Inc., the Babcock & Wilcox Company, and The Los Angeles Bureau of Power and Light for photographs supplied, and assistance rendered in the preparation of this booklet.

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